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The Scintillation and Tomography Receiver in Space (CITRIS) Instrument for Ionospheric Research

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Introduction: The ionosphere is a source of error and data loss for many communications, navigation, and radar systems. As satellite radio signals propagate from space through the ionosphere to the ground, they can become distorted by a large number of effects including phase fluctuations, Faraday rotation, amplitude fluctuations, group delay, absorption, scattering, frequency shifts, and multipath. Ionospheric characterization is needed to identify these influences, to predict their occurrence, and if possible, to mitigate their effects.

Radio beacon measurements of ionospheric total electron content (TEC) can be used by data assimilation models to improve ionospheric density specifications. Current assimilation models have been developed to incorporate many sources of ionospheric data including ground GPS TEC, bottom-side ionospheric profiles from ionosondes, and TEC from low-Earth-orbit (LEO) beacon transmissions to ground receivers. Until now, there has not been any beacon receiver in low Earth orbit that can provide rapid TEC and radio scintillation measurements from ground beacons and from other beacons in LEO.

The CITRIS Instrument: A new beacon receiver system called the Scintillation and Tomography Receiver in Space (CITRIS) is currently in orbit sampling the ionosphere. CITRIS was developed at NRL to (a) permit ionospheric measurements over the ocean and other remote areas of the Earth and (b) use the unique geometry of LEO-to-LEO satellite paths to determine absolute TEC and locate ionospheric scintillation regions.[1] The CITRIS receiver uses the frequency dispersion of the ionospheric plasma to remove frequency-independent effects like beacon-to-receiver range and neutral refractive index fluctuations. The CITRIS receiver tracks the Doppler-shifted changes in the radio beacon transmissions. With the highest frequency reference, the relative changes at the lower frequencies are captured in the CITRIS data. The variations of amplitude and phase in this data are due only to the ionosphere.

Sample Results: The CITRIS operations are scheduled based on orbit predictions for both the CITRIS receiver and beacon satellites. The NRL Coherent Electromagnetic Radio Tomography (CERTO) beacons on the COSMIC satellites[2] operating at 150 and 400 MHz provided the radio wave source for this example. An orbit segment is illustrated in Fig. 4 for the CERTO beacon satellite and for the STPSAT1 satellite with the CITRIS receiver. On 19 May 2007, the CITRIS receiver picked up the CERTO beacon signal along a 5000 km horizontal path when the tangent point was 270 km above the Earth's surface. At closest approach, the radio measurement was along a nearly vertical path of 232 km between COSMIC FM5 at 767 km altitude and STPSAT1 at 560 km altitude. After this, the satellite orbits diverged until the path was tangent to the orbit of the lower altitude STPSAT1 satellite with the CITRIS receiver. Further separation of the orbits caused the tangent altitude to drop below the CITRIS altitude until the signal was lost when the path intersected the Earth. No measurements were made when the tangent altitude was below the Earth's surface.

The minimum total electron current along the straight line between the satellites is found where the satellites are closest together (Fig. 5). The asymmetry in the curve of TEC versus intra-satellite distance demonstrates that the ionosphere is denser to the west of the satellite orbit crossing point. Geometric analysis is needed to convert the relative TEC provided by CITRIS to absolute values. The plot in Fig. 5 of TEC versus intra-satellite distance shows a linear variation near the point of closest approach (PCA). Extrapolation with the TEC curve to zero satellite separation sets the zero calibration point for the TEC values of the whole curve. This procedure is critical to providing absolute ionospheric measurements with an accuracy of 0.01 to 0.1 TECU where one TECU = 10^{16} electrons per m^2. This method of calibration is much better than other measurements of TEC such as GPS that rely on system calibrations that can only provide TEC with an accuracy of 1 to 3 TECU. The slopes of the lines near the PCA give the average electron density on each side.

With the assumption that the ionosphere is spherically symmetric, the Abel inversion technique can be used to estimate layer profiles. The CITRIS-CERTO geometry provides two occultation opportunities with two LEO satellite orbits. The TEC profiles from the occultation portion of the CITRIS observations show that the layer on the west side of the PCA is higher in altitude than the layer on the east side. Applying the Abel inversion to the TEC profile data yields the electron density profiles (Fig. 6). The primary reason for the layer differences is the latitude of the layers. The east layer region is near the equator at –8° geomagnetic latitude where the layer tends to be higher than at mid-latitudes. The west layer is near a mid-latitude region at –35° geomagnetic latitude.

Summary: The CITRIS receiver in low Earth orbit is acquiring high-accuracy TEC data to provide specifications of ionospheric TEC and derived electron density.

[Sponsored by ONR]

References

[1] P.A. Bernhardt, C.L. Siefring, I.J. Galysh, T.F. Rodilosso, D.E. Koch, T.L. MacDonald, M.R. Wilkens, and G.P. Landis, "Ionospheric Applications of the Scintillation and Tomography Receiver in Space (CITRIS) Mission when used with the DORIS Radio Beacon Network," in *J. Geodesy* **80**, 473-485 (2006).

[2] P.A. Bernhardt, C.A. Selcher, S. Basu, G. Bust, and S.C. Reising, "Atmospheric Studies with the Tri-Band Beacon Instrument on the COSMIC Constellation," Ch. 10 in L.-C. Lee, R. Kursinski, and C. Rocken, eds., *Applications of Constellation Observing System for Meteorology, Ionosphere & Climate*, p. 291-312 (Springer, Hong Kong, 2001). ★

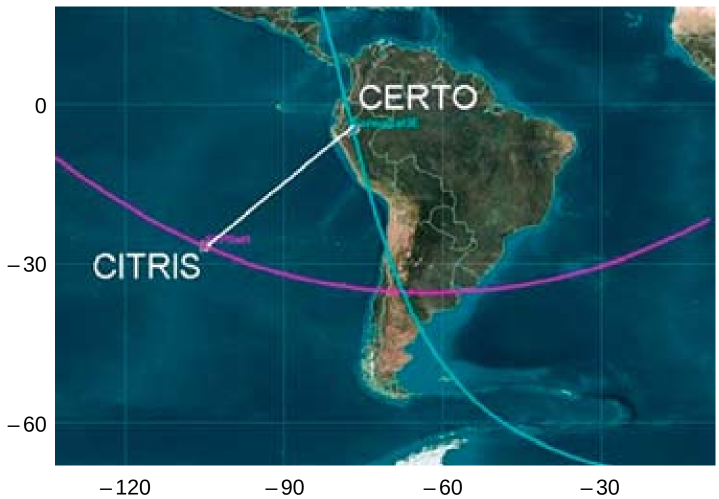

FIGURE 4
Orbit of CITRIS relative to the CERTO radio beacon transmitter on the COSMIC FM5 satellite. The orbits cross at a latitude of –35.5° N and a longitude of –68.0° E where the distance between the satellites is only 232 km.

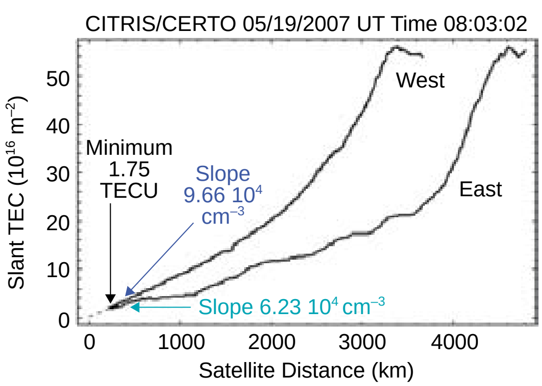

FIGURE 5
Measurements of total electron content (TEC) on the west and east side of the point of closest approach. Determination of absolute TEC uses extrapolation to zero separation between beacon and receiver satellites. The electron density is estimated from the derivative of the TEC with intra-satellite distance.

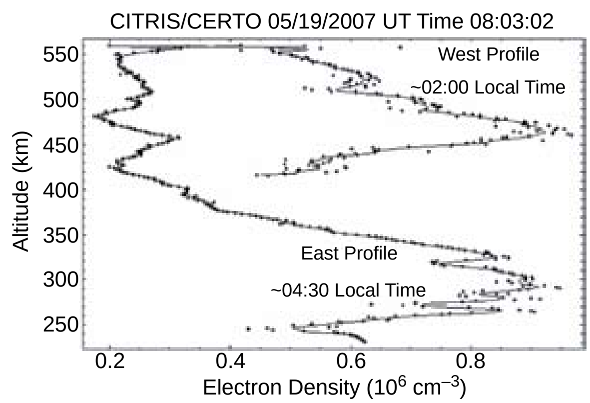

FIGURE 6
CERTO/CITRIS profiles of electron density. The dots are results of the Abel inversion with 1-km altitude separation in measured horizontal TEC. The solid line is the profile estimation using a 7-point running mean of the 1-km TEC samples.